EXPERIMENTAL RESULTS OF A HIGH POWER REP-RATE VELVET CATHODE

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Abstract

The primary goal of the Electromagnetic Sources Division of the Advanced Weapons and Survivability Directorate at the Phillips Laboratory is the development of high power microwave (HPM) devices for a variety of Air Force Applications. Recent interest has been in the rep-rate operation of traditionally single-shot HPM sources. Integral to this development is an understanding of the operation of velvet cathodes at multi-gigawatt power levels under rep-rate conditions. Velvet has been shown to emit very uniformly at relatively low field levels (<30 kV/cm), but suffers from the problem of outgassing during the beam pulse. This outgassing could cause the diode to short in subsequent pulses or a voltage breakdown in other areas of the microwave tube due to the increased pressure. Initial tests have been done to determine the feasibility of the application of velvet cathodes for rep-rate operation. These test were performed on the Phillips Laboratory Rep-Rate Pulser, a 5 Ohm, variable voltage, rep-rate device. This pulser can deliver 150-500 kV, 500 ns pulses to a 5 Ohm load at a rep-rate of a few Hz depending on the operating voltage. The temporal evolution of the pressure within the tube as a function of voltage was monitored during the tests to determine the maximum rep-rate dictated by the velvet cathode. The results of these experiments will be given in this paper.

System Description

The Phillips Laboratory Rep-Rate Pulser, which was used in these experiments, has been described in previous papers[1,2]. For this series of tests the output voltage was maintained between 300 kV and 400 kV and the pulser was operated at a maximum rep-rate of 10 Hz. The load is a magnetically insulated line oscillator (MILO)[3] currently under development by the Phillips Lab. A diagram of the MILO is shown in Fig. 1. The cathode is velvet that is attached to the cathode stalk with spray glue, the collector region of the beam dump is graphite and the rest of the tube is fabricated from aluminum. The vacuum is provided by a cryo-pump with a pumping speed of 1500 l/sec. located in the region of the vacuum interface and the pressure probe shown in Fig. 1 is a cold cathode gauge. Upon introduction of a voltage pulse, from the left in Fig. 1, there is emission from the cathode under the slow wave structure and in the beam dump region. Approximately 80% of the total current flows in the region of the beam dump and only 20% of the current flows under the slow wave structure. The current flowing under the slow wave structure is that which interacts with the electromagnetic wave to produce microwaves and the current in the beam dump serves to insulate the flow under the slow wave structure. This paper will focus on the operation of the diode and not upon the microwave generation characteristics of the experiment.

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14. ABSTRACT
The primary goal of the Electromagnetic Sources Division of the Advanced Weapons and Survivability Directorate at the Phillips Laboratory is the development of high power microwave (RPM) devices for a variety of Air Force Applications. Recent interest has been in the rep-rate operation of traditionally single-shot RPM sources. Integral to this development is an understanding of the operation of velvet cathodes at multi-gigawatt power levels under rep-rate conditions. Velvet has been shown to emit very uniformly at relatively low field levels (<30 kV /em), but suffers from the problem of outgassing during the beam pulse. This outgassing could cause the diode to short in subsequent pulses or a voltage breakdown in other areas of the microwave tube due to the increased pressure. Initial tests have been done to determine the feasibility of the application of velvet cathodes for rep-rate operation. These test were performed on the Phillips Laboratory Rep-Rate Pulser, a 5 Ohm, variable voltage, rep-rate device. This pulser can deliver 150-500 kV, 500 ns pulses to a 5 Ohm load at a reprate of a few Hz depending on the operating voltage. The temporal evolution of the pressure within the tube as a function of voltage was monitored during the tests to determine the maximum rep-rate dictated by the velvet cathode. The results of these experiments will be given in this paper.

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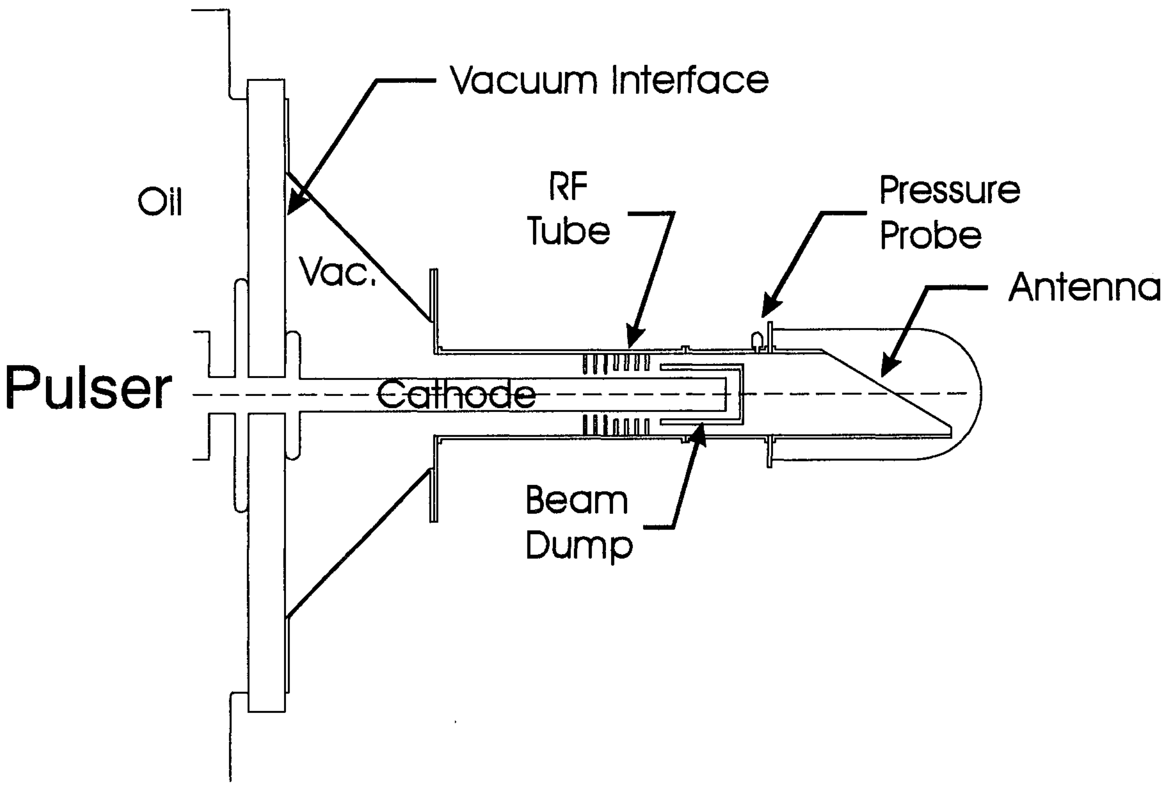

Figure 1. Diagram of the Experimental Configuration.

Experimental Data

The experimental procedure was to start a relatively low voltage and low rep-rate and incrementally increase both operational parameters to investigate the effect. Initially the charge voltage was set to 25 kV which corresponds approximately to 300 kV on the diode. The results of these experiments are shown in Figs. 2-6. Figure 2 shows the experimental waveforms for a 10 pulse, 5 Hz shot series with a charge voltage of 25 kV. For these settings the energy content of the beam and the energy flux is approximately 3.9 kJ/pulse and 19.5 kJ/sec. respectively. There is no detectable degradation of the pulse over the pulse string. Referencing the pressure graph of Fig. 2 it can be seen that the output switch of the pulser did not close on the second pulse, indicated the absence of a pressure increase 200 ms after the pressure increase caused by the first pulse. After that the pressure steadily increased with each subsequent pulse to steady state value of about 2.5 mTorr on the sixth pulse. The data shown in Fig. 3 is for a 10 pulse, 10 Hz, 25 kV charge burst. The energy content of the beam for this case is identical to that shown in Fig. 2, but the energy flux has doubled to 39 kJ/sec. There is severe pulse degradation during the burst. In this case the pressure in the diode region increased above 3 mTorr where the diode behaves very erratically. Figures 4 and 5 show the results of 10 pulse bursts at a charge voltage of 30 kV for rep-rates of 5 Hz and 10 Hz respectively. It is most fortuitous that the operational parameters demonstrated in Fig. 4 were chosen because this data shows the onset of pulse degradation. The energy per pulse is 5.5 kJ, the energy flux is 27.5 kJ/sec. and the pressure in the diode region increases to between 2.5 mTorr and 3 mTorr. This is interpreted as the threshold of the energy flux and pressure increase to cause pulse degradation. The 10 pulse, 10 Hz, 30 kV charge data shown in Fig. 5 illustrates severe pulse degradation. Once again the energy per pulse is 5.5 kJ but the energy flux has doubled to 55 kJ/sec. It should be noted that the ninth pulse of the burst has improved slightly in comparison to the fifth pulse, probably attributed to the fact that the pressure within the diode region has dropped below the 2.5 mTorr threshold. Once the pressure approaches 3 mTorr the diode is performing so poorly that less power is being delivered by the beam or less power is being dissipated in the graphite beam dump, allowing the vacuum to recover somewhat.

Observations

Although no concrete conclusions can be drawn from the results of these tests, a number of observations can be made:

- For a 5 Hz, 10 pulse burst there is no pulse degradation at a diode voltage of 300 kV
- For a 5 Hz, 10 pulse burst there is slight pulse degradation at a diode voltage of 400 kV
- For a 10 Hz, 10 pulse burst there is severe pulse degradation at a diode voltages of 300 and 400 kV
- For background pressures less than 2.5 mTorr there is no pulse degradation
- Pulse degradation occurs for background pressures greater than 2.5 mTorr
- For a beam energy flux less than 19.5 kJ/sec. there is no pulse degradation
- For a beam energy flux of 27.5 kJ/sec. there is slight pulse degradation
- For a beam energy flux greater than 39 kJ/sec. there is severe pulse degradation.

It is unclear as to the source of the pressure increase but it is postulated that it is the graphite beam dump heating up and outgassing and/or the velvet outgassing during emission. Another important observation from these experiments is that in the course of many rep-rate bursts and the associated cycling of the pressure within the vacuum chamber, the vacuum interface on the pulser gets coated with debris, which causes the interface to flashover above voltages of 400 kV. When the interface is free of this coating the machine can be operated at voltages above 500 kV reliably.

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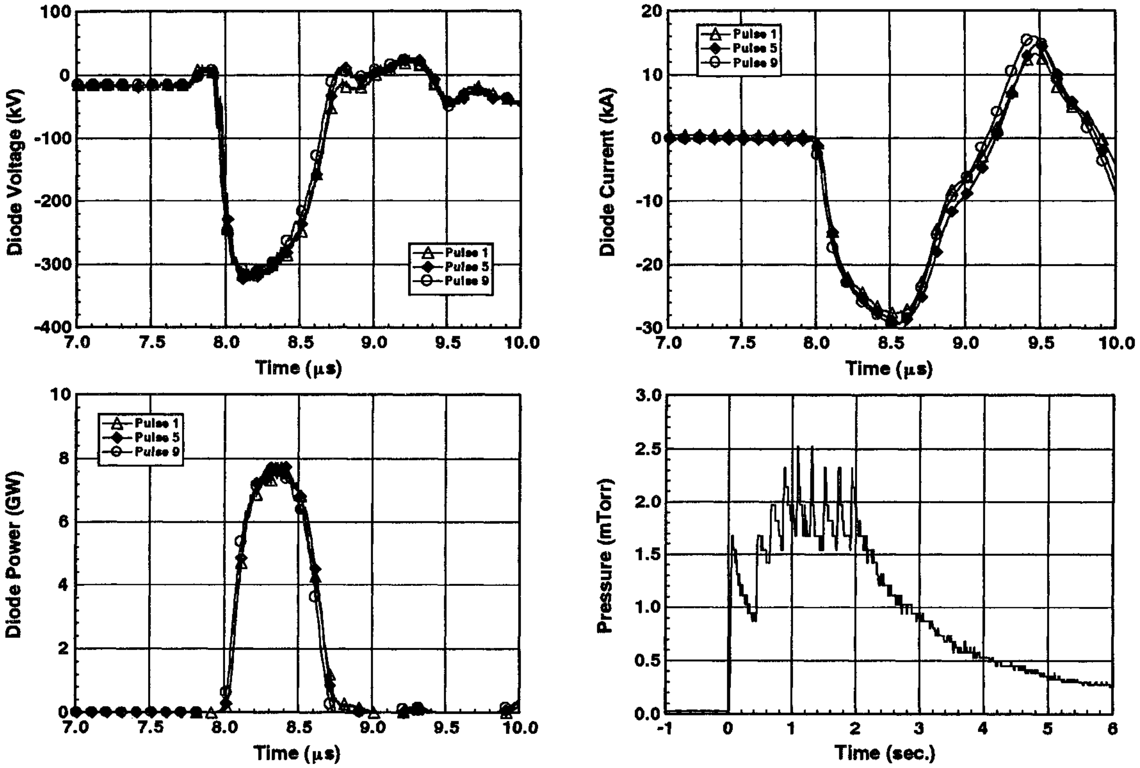

Figure 2. Diode Voltage, Current, Power, and Base Pressure for a 10 Pulse, 5 Hz, 25 kV Charge Shot Series.

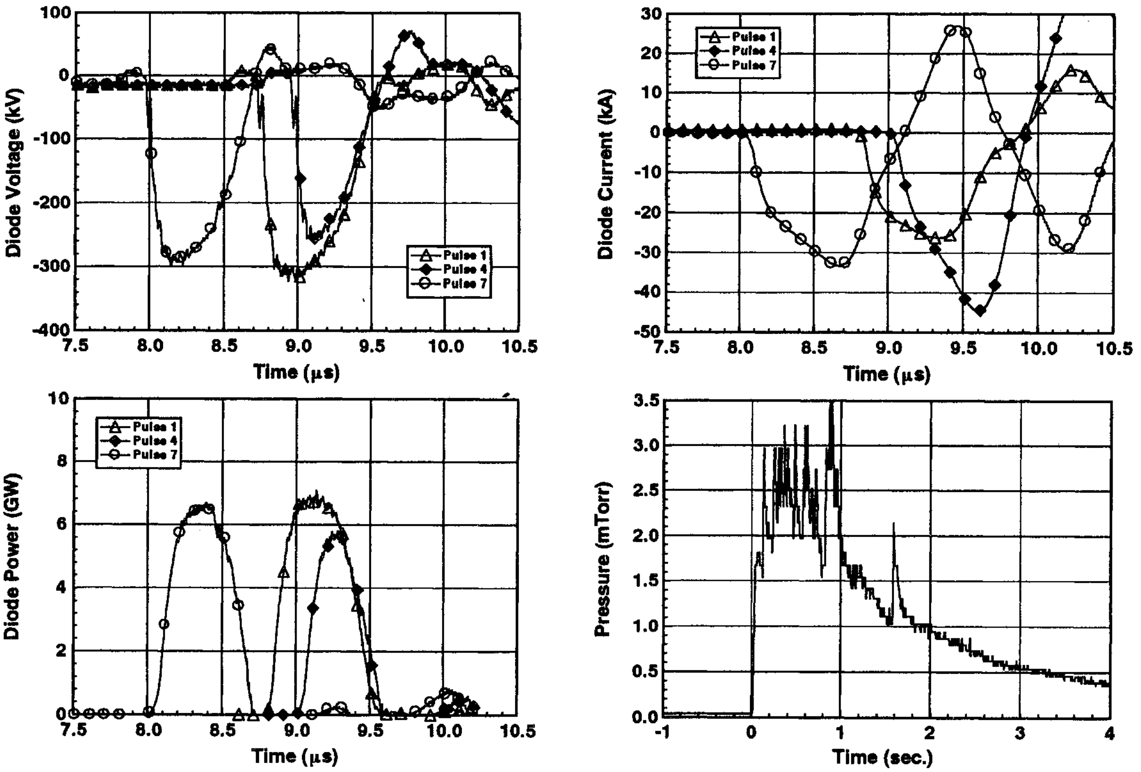

Figure 3. Diode Voltage, Current, Power, and Base Pressure for a 10 Pulse, 10 Hz, 25 kV Charge Shot Series

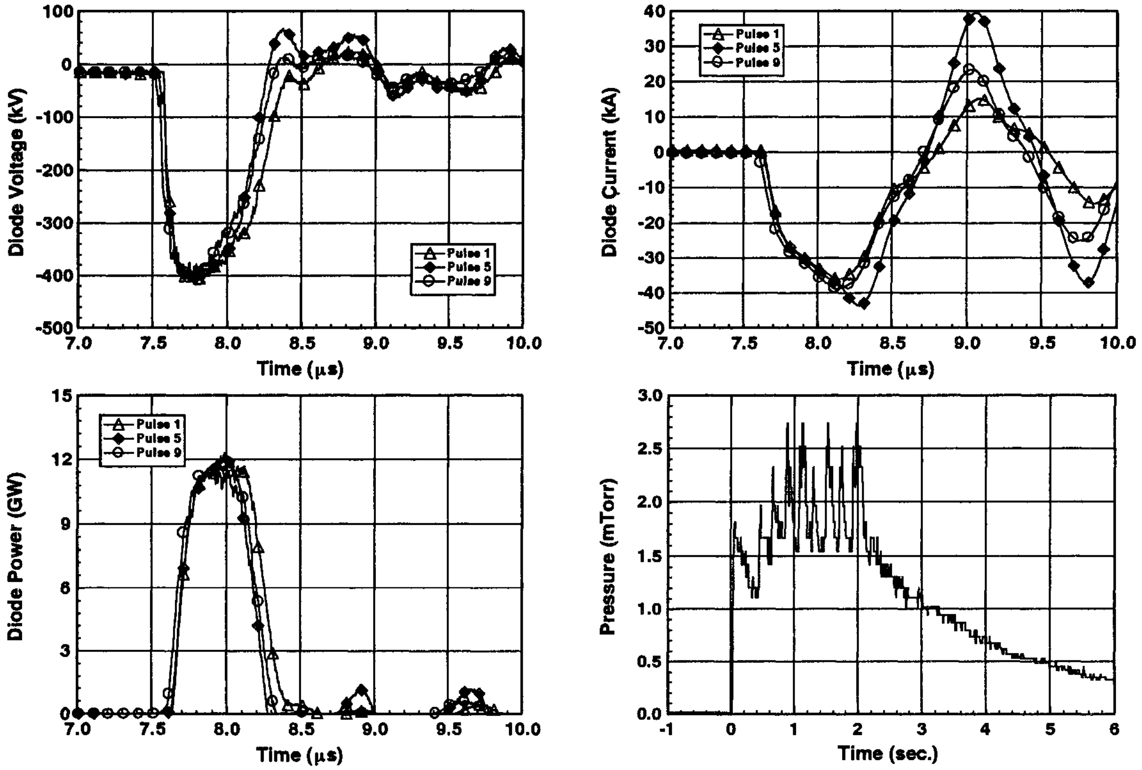

Figure 4. Diode Voltage, Current, Power, and Base Pressure for a 10 Pulse, 5 Hz, 30 kV Charge Shot Series.

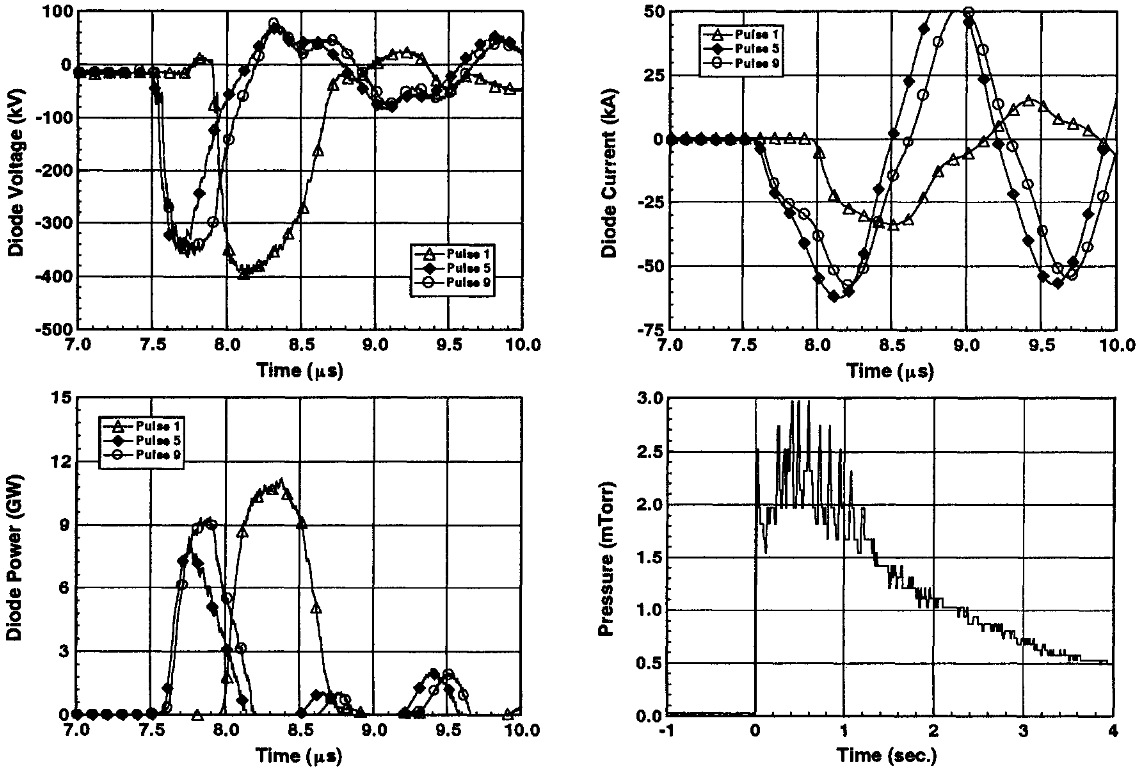

Figure 5. Diode Voltage, Current, Power, and Base Pressure for a 10 Pulse, 10 Hz, 30 kV Charge Shot Series